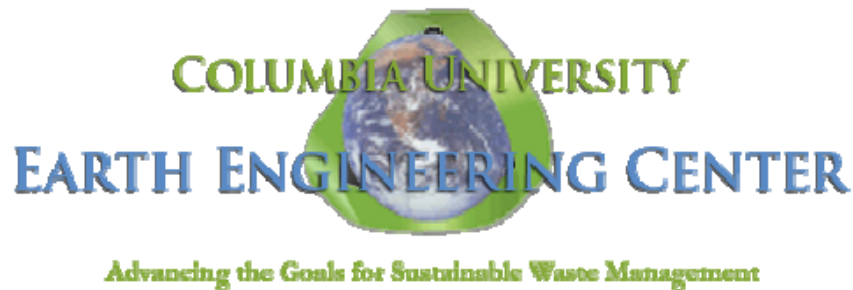# ENERGY AND ECONOMIC VALUE OF NON-RECYCLED PLASTICS (NRP) AND MUNICIPAL SOLID WASTES (MSW) THAT ARE CURRENTLY LANDFILLED IN THE FIFTY STATES

A study by

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Advancing the Goals for Sustainable Waste Management

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ENERGY AND ECONOMIC VALUE OF NON-RECYCLED PLASTICS (NRP) AND MUNICIPAL SOLID WASTES (MSW) THAT ARE CURRENTLY LANDFILLED IN THE FIFTY STATES

EXECUTIVE SUMMARY

Mechanical recycling of plastics has continued to grow in the United States, with 2.1 million tons of plastics recycled in 2009. This includes recovery of used plastics from polyethylene terephthalate (PET), high density polyethylene (HDPE) bottles, non-bottle rigid containers, and some flexible packaging. However, despite the efforts of many communities to source-separate plastics, less than 15% of the U.S. post-consumer plastics are being diverted from landfills by means of recycling and energy recovery. Therefore, while continuing its efforts to increase plastics recycling, the American Chemistry Council (ACC) is also seeking ways to recover more of the energy value of underlined non-recycled plastics (NRP) in the form of electricity, heat, or petrochemical feedstock. Landfilling of NRP constitutes a loss of a valuable energy resource. Capturing the energy value of non-recycled plastics will contribute to sustainable development and enhance national energy security.

The Plastics Division of ACC requested the Earth Engineering Center of Columbia University (EEC) to quantify the amount of plastics discarded in each state and their disposition to materials recovery (recycling), energy recovery in waste-to-energy plants (WTE), and to landfills. EEC was also asked to calculate the energy value of NRP currently going to landfills and identify ways for recovering the energy content of this valuable energy resource.

Key Findings

- The results of this study showed that 6.5% of the used plastics generated in the U.S. are recycled, 7.7% are combusted with energy recovery, and the remaining 85.8% are landfilled. The states closest to sustainable waste management of plastics in 2008, by complementing recycling with energy recovery, are Connecticut, Massachusetts, Hawaii, Maine, Virginia, and Minnesota; the diversion rates of NRP from landfills in these states, by recycling and combustion with energy recovery, range from 65% for Connecticut to 32% for Minnesota.

- The amount of NRP plastics landfilled in the United States in 2008 was estimated at 28.8 million tons. The chemical energy contained in this material was 807 trillion Btu. This amount of energy is equivalent to:

  - 36.7 million tons of coal, or
  - 139 million barrels of oil, or
  - 783 billion cubic feet of natural gas

- Hypothetically, if all the NRP that are currently landfilled were source-separated and converted by pyrolysis to a fuel oil, they would produce an estimated 87 million barrels of oil per year (3.6 billion gallons), enough to power six million cars for one year.

- If all the NRP that are landfilled annually were to be source-separated and used as fuel in specially designed power plants, the electricity produced would be 52 million MWh, enough to supply 5.2 million households. This would also reduce U.S. coal consumption by as much as 34 million tons.

- Hypothetically, if 100% of the landfilled municipal solid wastes (MSW) were diverted from landfills to new WTE power plants, they would reduce coal consumption by 108 million tons and produce 162 million MWh of electricity, enough to power 16.2 million households for one year.

- This study also examined the effect of new WTE capacity on reducing coal consumption in states that now import large amounts of coal. As stated above, one ton of MSW used as fuel in new WTE plants would produce the energy equivalent of about 0.4 tons of coal. Accordingly, 25% diversion of MSW currently landfilled to new WTE plants would avoid the mining of 27 million tons of coal and as much as 270 million tons of overburden; 100% diversion of current landfilling by means of new WTE capacity would reduce coal mining by 108 million tons of coal, nearly 10% of the U.S. coal consumption.

- Lastly, increased WTE capacity would reduce the carbon footprint of waste management in the U.S. For example, a 25% diversion of mixed biomass and NRP in MSW from landfills to new WTE facilities will result in greenhouse gas (GHG) reduction of 35 to 70 million tons of carbon dioxide equivalent, depending on the degree of landfill capture in present landfills.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

1.1 The need for this project

Over the years, the rate of plastics recycling in the United States has increased, reaching 2.1 million tons by 2009; the progress made in recycling plastics and the obstacles in recycling some plastic packaging are described in detail in the Columbia University M.S. thesis of Jawad Bhatti (15). The American Chemistry Council (ACC) is seeking ways to reduce the amount of plastics landfilled and complement mechanical recycling by recovering the energy value from the millions of tons of post-consumer plastics that are currently being landfilled.

As the United States seeks alternative fuel sources, projects like this – which help quantify the scale and availability of an energy source – are crucial to helping identify renewable fuel sources for policy makers.
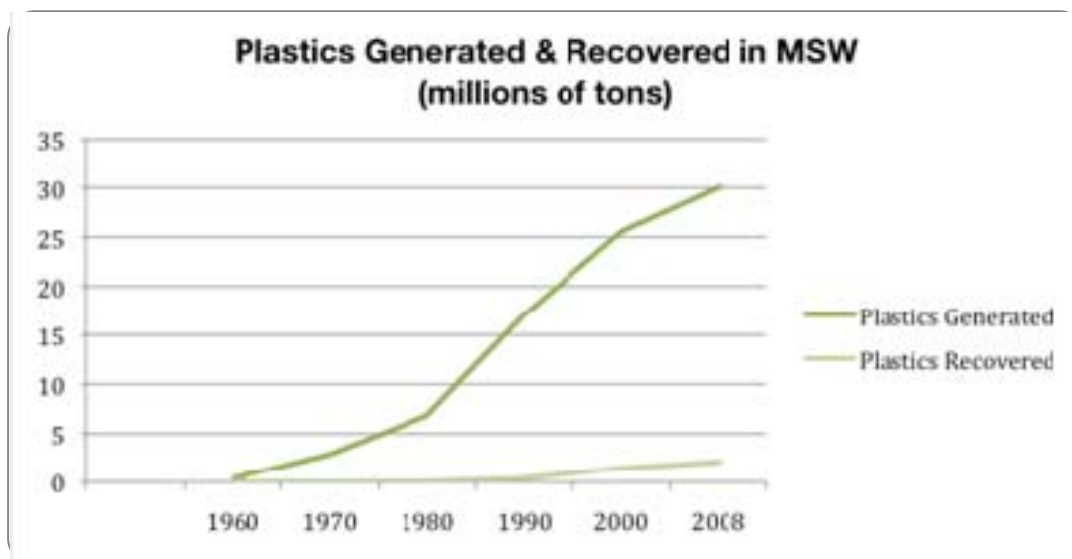
Figure 1 Plastic wastes generated and recycled since 1960 (20)

The ACC is seeking to quantify the energy value and potential economic value of non-recycled plastics (NRP) that are mixed in municipal solid wastes (MSW) and currently not used for energy recovery via thermal treatment technologies (e.g. mass burn, RDF, SRF, gasification, pyrolysis, etc.). Since plastics have an energy value higher than coal, landfilling of non-recycled plastic wastes constitutes a loss of an important energy resource. The Earth Engineering Center of Columbia University was engaged by ACC to conduct a scientific study of this subject, the results of which are presented in this Report.

1.2 The project team

The Earth Engineering Center of Columbia University (EEC; ref. 16) is an academic research group recognized internationally for its extensive research and publication record on materials and energy recovery from solid wastes. EEC also conducts the bi-annual

BioCycle/Columbia survey of waste generation and management, the results of which are used by EPA in estimating greenhouse gas (GHG) effects of waste management (17). EEC has also collaborated with the Office of Energy Conservation and Recovery of EPA in the development of the new EPA web page on Energy Recovery from Wastes.

Since its foundation in 1997, EEC has sponsored dozens of graduate research theses on all aspects of waste management, especially those relating to reducing the carbon footprint of waste management by recovering energy, in the form of electricity, heat and fuels. This research has led to many scientific and technical papers (5). EEC has a wide global presence through its Waste-to-Energy Research and Technology Council (WTERT, www.wtert.org) an academic-industrial consortium sponsored by the major waste management companies in the U.S. and abroad. WTERT has sister organizations in Brazil (www.wtert.br), China (www.wtert.cn), Germany (www.wtert.eu), Greece (www.wtert.gr), and Japan (www.wtert.jp). Other units are under development in Argentina, Chile, France, Italy, India and the U.K.

The guiding principle of all EEC research is that responsible management of wastes must be based on science and the best available technology and not on ideology and economics that exclude environmental costs. The Research Associates of EEC include Columbia engineers from various disciplines as well as specialists from other universities and organizations, on whom EEC can call for technical advice as required. Figure 2 shows the Hierarchy of Sustainable Waste Management developed by EEC (18).

Figure 2 The EEC Hierarchy of Waste Management (18)

1.3   Scope of work

The stated objectives of this study were to identify and collect information on non-recycled plastics (NRP) that are currently landfilled in the 50 states of the Union; and then quantify the potential energy and economic value of recovering all this material.
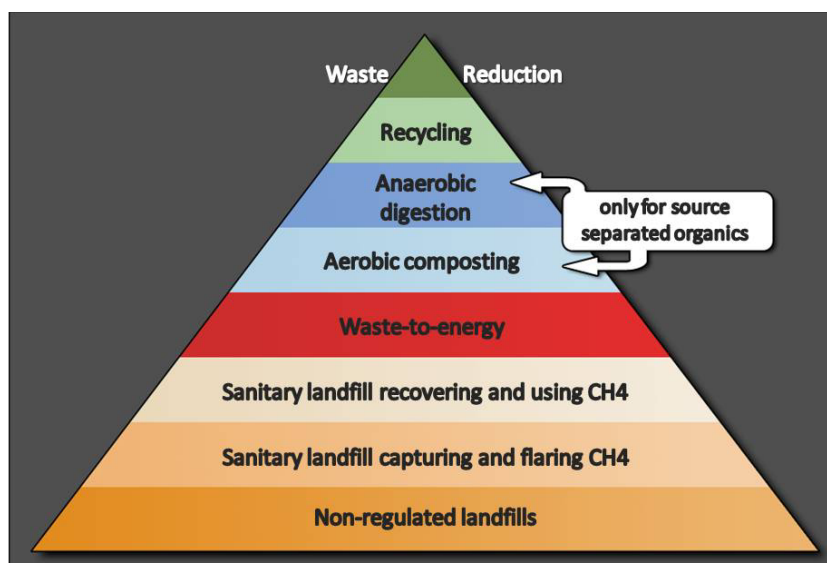
1.4 Methodology

The EPA 2008 report of post-consumer plastics divides used plastics into several categories that add up to a total of 30.2 million tons. However, the actual tonnage may be higher, because of imports from China and other countries. Our extrapolation of data from a detailed characterization of plastics in the MSW of California to the U.S. population showed that the U.S. generation of used plastics in 2008 was at least 33.6 million tons which is the tonnage used in this study.

The national amount of discarded plastics in 2008 (33.6 million tons) was then apportioned among the fifty states by population. The distribution of recycled plastic volumes among the fifty states was based on state total recycling rates and also on total capacity of Materials Recovery Facilities (MRF) within a state. In most cases, the calculated values of tons of plastic recycled in a state by these two methods were in good agreement.

The tonnage of plastics combusted with energy recovery in states that have WTE plants was calculated by assuming that the reported MSW to WTE plants contained 10% plastic; this was a conservative estimate in view of published characterization studies in several states and the EPA estimate of plastics concentration in the MSW stream (see Section 2). Finally, the tonnage of plastics landfilled in a state was obtained by subtracting plastics recycled and combusted from the estimate of plastics discarded in each state:

Tons of NRP to LF = tons of plastics discarded - tons plastics recycled - tons of plastic combusted in WTE plants

The results of the study showed that of the 33.6 million tons of post-consumer plastics, 2.2 million tons (6.5% of total plastics in MSW) were recycled, 2.6 million tons (7.7%) were combusted with energy recovery, and 28.9 million tons (85.8%) were landfilled.

2   ESTIMATE OF U.S. GENERATION OF PLASTIC WASTES

Table 1 shows that the EPA reported (19) that about 30 million tons of used plastics were generated in the U.S. On the other hand, various MSW composition studies conducted across the nation (Table 2, ref. 1-12) have shown that municipal solid wastes (MSW) contain anywhere from 9.6% (California) to 17% (New York) of non-recycled plastics (NRP). Also, EPA has reported that, on the average, U.S. MSW contains 12% plastics; if this number is applied to the recorded tonnage of MSW landfilled and combusted (296 million) in the U.S. (Columbia/BioCycle State of Garbage survey of 2008 data; ref. 14), the calculated tonnage of non-recycled plastics would be 35.5 million tons. Adding to this amount the estimated 2.1 million tons of recycled plastics brings the total generation of plastics in MSW to 37.6 million. These numbers indicate that the EPA estimate of 30 million tons is somewhat low. As noted earlier, in this study we assumed that the plastic generated was halfway between these two numbers, at 33.6 million tons. Apportioning this tonnage among the fifty states, on the basis of population, is in agreement with the reported generation of about four million tons of plastic wastes in California (see Table 8 of APPENDIX 1).

Table 1 Generation, recycling, and disposal of plastics in the U.S. in 2008 in thousand tons (20)

	Generated	Recycled	Landfilled/ WTE
Durable Goods	*10,520*	*390*	*10,130*
Non-durable Goods:			
Cups and plates	780	Negligible	
Trash bags	930	Negligible	
Other non-durables	4,810	negligible	
Total non-durables	*6,520*		*6,520*
Containers/packaging:			
Bottles/jars, PET	2,680	730	
Bottles/jars, HDPE	750	220	
Other containers	1,900	280	
Bags, sacks, wraps	3,960	390	
Other packaging	3,720	110	
Total containers/packaging	*13,010*	*1,730*	*11,280*
Total plastics	**30,050**	**2,120**	**27,930**

Table 2 MSW composition studies at various states (1-12)

State	Year	Paper	Glass	Metals	Plastics	Organic
California[1]	2008	17.30%	1.40%	4.60%	9.60%	32.40%
Connecticut[2]	2010	25.90%	2.10%	4.50%	14.70%	26.70%
Delaware [3]	2007	25.70%	2.40%	5.20%	11.10%	25.10%
Georgia[4]	2005	38.70%	3.70%	5.40%	15.80%	27.10%
Minnesota[5]	2000	34.30%	2.80%	5.10%	11.40%	25.70%
New York [6]	2010	27.00%	3.00%	6.00%	17.00%	24.00%
Iowa[7]	2005	26.17%	1.36%	3.74%	11.78%	17.46%
Maryland [8]	2006	27.00%	2.60%	3.80%	14.40%	45.90%
Oregon [9]	2009	16.99%	1.95%	5.45%	11.56%	50.21%
Pennsylvania [10]	2003	33.30%	3.00%	5.40%	11.30%	34.20%
Washington [11]	2009	19.20%	2.40%	6.30%	11.40%	27.20%

3   ESTIMATE OF MSW RECYCLED, COMBUSTED AND LANDFILLED IN EACH STATE

In order to estimate the tons of plastic wastes recycled, combusted and landfilled in each State, we need to know the disposition of MSW in each state. The only source of state-by-state data is the Columbia/BioCycle "State of Garbage" survey. It is based on detailed

questionnaires sent to the waste management departments of each state and subsequent analysis of these data. In 2008, the fifty states reported to the Columbia/BioCycle survey that a total of 270 million tons of MSW was disposed in U.S. landfills, while the EPA estimated (7) that only 136 million tons were landfilled in the same year. It should be noted that the EPA departments dealing with greenhouse gas (GHG) emissions of waste management use the Columbia/BioCycle numbers. The Earth Engineering Center and also the Energy Recovery Council has brought this serious discrepancy to the attention of EPA management; currently EPA is soliciting stakeholder input "regarding the efficacy and scope of the MSW Characterization Report called "Municipal Solid Waste in the United States". This information will be used to develop new measurement definitions and protocols for measurement of these materials. This effort could lead to the creation of a new measurement report that EPA will make publicly available.
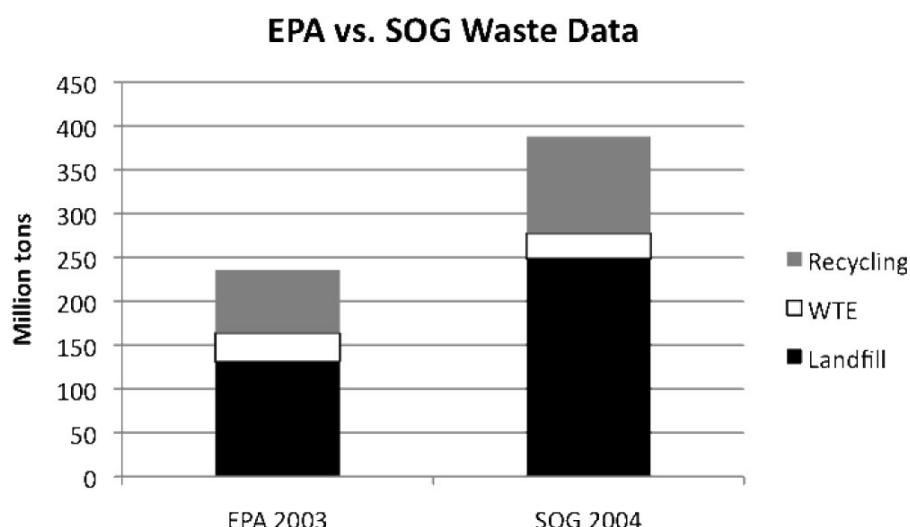

Figure 3 Comparison of EPA "Facts and Figures" and SOG data *(ref.19; EPA did not report MSW data for 2004 and there was no Columbia/BioCycle national survey in 2003)*

Figure 4 shows the reported tons landfilled in each state. Table 3 shows the distribution of MSW into recycling, WTE and landfilling in each state, as reported to the Columbia/BioCycle national survey of 2008 data.
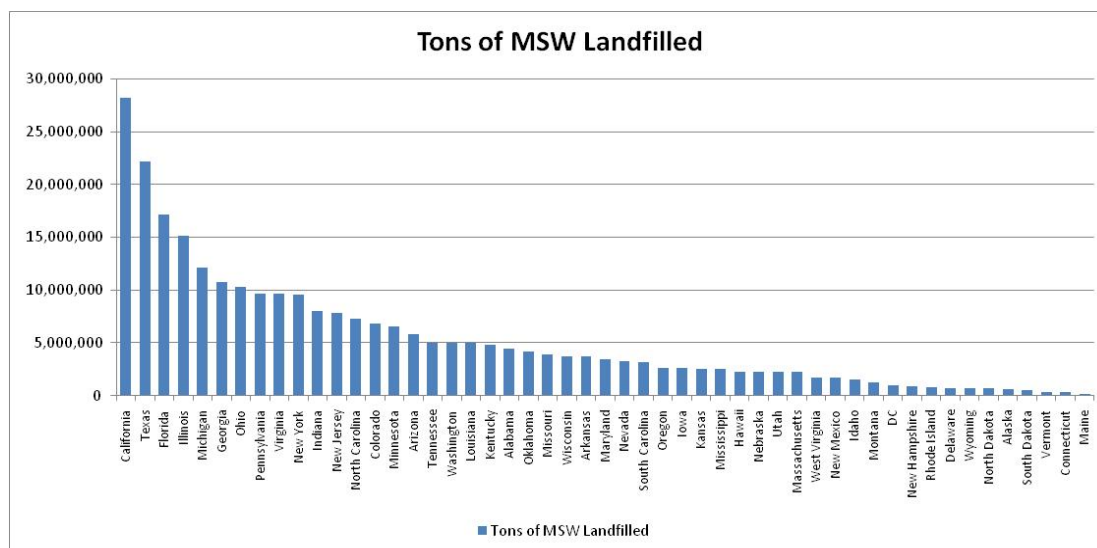
Figure 4 Tons of MSW landfilled in fifty states

Table 3 MSW generated, recycled, combusted and landfilled in 2008 (14)

State	Population	Total tons of MSW	Tons MSW recycled	Tons MSW to WTE	Tons MSW landfilled
Alabama	4,661,900	*5,287,330*	472,000	316,659	4,498,671
Alaska	686,293	*643,253*	28,646	0	614,607
Arizona	6,500,180	*6,784,535*	917,373	0	5,801,208
Arkansas	2,855,390	*4,696,134*	483,896	0	3,711,017
California	36,756,666	*61,210,578*	24,724,726	627,039	28,216,903
Colorado	4,939,456	*7,475,820*	540,141	0	6,824,960
Connecticut	3,501,252	*3,489,034*	607,691	2,190,873	387,542
Delaware	873,092	*1,032,201*	168,701	0	741,143
DC	591,833	*1,031,083*	21,142	12,791	997,150
Florida	18,328,340	*23,335,009*	2,403,281	3,770,416	17,161,312
Georgia	9,685,744	*11,529,102*	682,266	41,350	10,765,486
Hawaii	1,288,198	*3,718,002*	574,294	589,982	2,297,680
Idaho	1,523,816	*1,668,578*	150,172	0	1,518,406
Illinois	12,901,563	*16,650,811*	1,003,390	0	15,150,000
Indiana	6,376,792	*9,455,000*	480,176	586,493	8,012,706
Iowa	3,002,555	*3,894,330*	924,364	69,537	2,652,855
Kansas	2,802,134	*3,473,325*	727,853	0	2,597,584
Kentucky	4,269,245	*6,335,476*	1,185,541	63,700	4,827,483
Louisiana	4,410,796	*5,835,476*	29,800	259,000	4,981,510
Maine	1,316,456	*1,186,854*	333,132	607,463	217,290
Maryland	5,633,597	*6,551,880*	1,461,164	847,659	3,461,764
Massachusetts	6,497,967	*8,350,000*	2,300,000	3,133,200	2,236,800
Michigan	10,003,422	*14,011,339*	844,328	1,081,011	12,086,000
Minnesota	5,220,393	*10,326,122*	2,589,954	1,187,600	6,530,938
Mississippi	2,938,618	*2,698,238*	129,839	0	2,553,238
Missouri	5,911,605	*4,851,821*	951,860	0	3,899,961
Montana	967,440	*1,438,084*	66,662	0	1,317,324

Nebraska	1,783,432	*2,565,379*	322,500	0	2,242,879
Nevada	2,600,167	*3,614,681*	229,128	0	3,299,832
New Hampshire	1,315,809	*1,244,365*	89,739	254,040	877,148
New Jersey	8,682,661	*13,169,025*	2,012,583	1,400,000	7,842,764
New Mexico	1,984,356	*2,031,891*	230,865	0	1,755,747
New York	19,490,297	*16,925,888*	3,060,363	3,681,134	9,556,442
North Carolina	9,222,414	*8,630,060*	668,498	107,837	7,264,586
North Dakota	641,481	*736,872*	26,695	0	687,394
Ohio	11,485,910	*13,252,219*	2,037,688	0	10,337,719
Oklahoma	3,642,361	*4,394,393*	170,000	0	4,224,393
Oregon	3,790,060	*4,632,513*	1,421,850	181,666	2,689,119
Pennsylvania	12,448,279	*17,043,945*	4,677,083	1,951,447	9,666,692
Rhode Island	1,050,788	*1,014,846*	101,883	0	864,583
South Carolina	4,479,800	*4,448,935*	914,056	212,118	3,155,304
South Dakota	804,194	*699,039*	71,041	0	565,148
Tennessee	6,214,888	*5,414,776*	251,112	74,327	5,039,337
Texas	24,326,974	*29,164,982*	2,634,275	0	22,170,707
Utah	2,736,424	*2,580,879*	51,159	126,739	2,241,353
Vermont	621,270	*584,467*	120,499	33,246	394,610
Virginia	7,769,089	*14,858,903*	2,716,198	2,135,407	9,627,472
Washington	6,549,224	*7,420,559*	1,461,403	332,301	4,986,236
West Virginia	1,814,468	*2,110,381*	337,661	0	1,772,720
Wisconsin	5,627,967	*5,150,553*	831,552	51,250	3,727,151
Wyoming	532,668	*839,060*	43,745	0	729,647
Total	**304,059,724**	**389,488,026**	**69,283,968**	**25,926,285**	**269,780,521**

4 ESTIMATE OF PLASTICS RECYCLED, COMBUSTED, AND LANDFILLED IN EACH STATE

4.1 Tons of plastic wastes generated in each state

The estimated total tons of plastics generated in the U.S. (33.6 million tons) were apportioned to each state on the basis of its population.

4.2 Tons of plastic wastes recycled in the U.S.

The American Chemistry Council (21) estimated that the recycled non-durable plastics in 2008 amounted to 1.82 million tons (Table 4). Adding to this number the 0.39 million estimate of recycled durable plastics by EPA (20) resulted in the total of 2.2 million tons of plastics recycled in 2008, which was the number used in this study.

Table 4 Estimate of 2008 Plastic Recycling by EPA (20) and ACC (21)

Component of plastic stream	Tons	%
PET bottles	722,000	32.60%
HDPE bottles	490,000	22.20%
PP bottles	13,500	0.60%

Bags/films	416,000	18.80%
Non-bottle rigid plastics	180,000	8.10%
ACC total of recycled non-durable goods	1,821,500	82.40%
EPA estimate of recycling of durable goods	390,000	17.60%
Total tons of plastics recycled	2,211,500	100.00%

4.3 Tons of plastic wastes recycled in each state

The estimated 2.2 million tons of plastic recycled in the U.S. were distributed among the states in two ways:

a) According to the ratio of

> *tons of MSW recycled in state/ tons of MSW recycled in the U.S.*

For the purposes of this report, it was assumed that states that recycle a large fraction of their MSW, such as paper, glass, aluminum and ferrous objects, also have comparable recycling programs for their mixed plastics.

b) A detailed calculation was made of the Materials Recovery Facilities (MRF) capacity in each state. The total plastic recycled was then apportioned according to the ratio

> *tons of MRF capacity in state/tons of U.S. MRF capacity.*

Table 5 shows the calculated numbers of "% of U.S. recycling" and "% of U.S. MRF capacity" for the fifty states. The results of distribution (a) and (b) were compared and for most states were in good agreement. The average of the (a) and (b) values for each state was taken as the best estimate of tons of plastic recycled in the state.

Table 5 2008 distribution of MSW recycled and MRF capacity in the fifty states

State	Tons recycled (SOG 2010)	% of total U.S. recycling	Tons of MRF capacity (Berenyi)	% of U.S. MRF capacity
Alabama	472,000	0.70%	236,000	1.10%
Alaska	28,646	0.00%	24,530	0.11%
Arizona	917,373	1.30%	474,613	2.21%
Arkansas	483,896	0.70%	14,619	0.07%
California	24,724,726	35.70%	2,848,096	13.26%
Colorado	540,141	0.80%	452,375	2.11%
Conn.	607,691	0.90%	414,932	1.93%
Delaware	168,701	0.20%	61,034	0.28%
DC	21,142	0.00%	3,380	0.02%
Florida	2,403,281	3.50%	1,066,021	4.96%
Georgia	682,266	1.00%	341,134	1.59%
Hawaii	574,294	0.80%	77,038	0.36%
Idaho	150,172	0.20%	94,958	0.44%

Illinois	1,003,390	1.40%	1,035,719	4.82%
Indiana	480,176	0.70%	240,087	1.12%
Iowa	924,364	1.30%	419,214	1.95%
Kansas	727,853	1.10%	336,000	1.56%
Kentucky	1,185,541	1.70%	124,754	0.58%
Louisiana	29,800	0.00%	29,800	0.14%
Maine	333,132	0.50%	80,886	0.38%
Maryland	1,461,164	2.10%	859,380	4.00%
Mass.	2,300,000	3.30%	604,100	2.81%
Michigan	844,328	1.20%	387,004	1.80%
Minnesota	2,589,954	3.70%	464,658	2.16%
Mississippi	129,839	0.20%	24,000	0.11%
Missouri	951,860	1.40%	536,013	2.50%
Montana	66,662	0.10%	9,324	0.04%
Nebraska	322,500	0.50%	129,000	0.60%
Nevada	229,128	0.30%	114,564	0.53%
New Hampshire	89,739	0.10%	75,417	0.35%
New Jersey	2,012,583	2.90%	1,515,169	7.05%
New Mexico	230,865	0.30%	14,976	0.07%
New York	3,060,363	4.40%	2,229,235	10.38%
North Carolina	668,498	1.00%	319,100	1.49%
North Dakota	26,695	0.00%	24,000	0.11%
Ohio	2,037,688	2.90%	541,469	2.52%
Oklahoma	170,000	0.20%	44,760	0.21%
Oregon	1,421,850	2.10%	572,180	2.66%
Pennsylvania	4,677,083	6.80%	1,003,510	4.67%
Rhode Island	101,883	0.10%	97,000	0.45%
South Carolina	914,056	1.30%	273,629	1.27%
South Dakota	71,041	0.10%	49,823	0.23%
Tennessee	251,112	0.40%	218,388	1.02%
Texas	2,634,275	3.80%	979,581	4.56%
Utah	51,159	0.10%	91,250	0.42%
Vermont	120,499	0.20%	67,603	0.31%
Virginia	2,716,198	3.90%	577,405	2.69%
Washington	1,461,403	2.10%	735,510	3.42%
West Virginia	337,661	0.50%	13,769	0.06%
Wisconsin	831,552	1.20%	535,409	2.49%
Wyoming	43,745	0.10%	NA	NA
Total	**69,283,968**	**100.00%**	**21,482,414**	**100.00%**

4.4 Tons of plastic combusted in each state

As was shown earlier, the measured plastic content of MSW is between 9.6% and 17%. As stated earlier, this study assumed that the reported MSW to WTE facilities in each state contained 10% plastic wastes.

4.5 Estimate of plastic wastes landfilled

The tons of non-recycled plastics landfilled in each state were calculated by subtracting the plastics recycled and combusted from the plastics generated in each state.

4.6 Results of calculations

The results of this study showed that 6.5% of the plastic generated is recycled, 7.7% is combusted with energy recovery and 85.7% is landfilled. A state-by-state comparison of how much plastic is recycled, recovered for energy, and landfilled in each state is shown in graphical form in Figure 5 and Figure 6. It can be seen that the states at the top of the graph, and thus closest to sustainable waste management, are Connecticut, Massachusetts, Hawaii, Maine, Virginia, and Minnesota. **It should be noted that states that have WTE capacity also have relatively high rates of plastic recycling.**

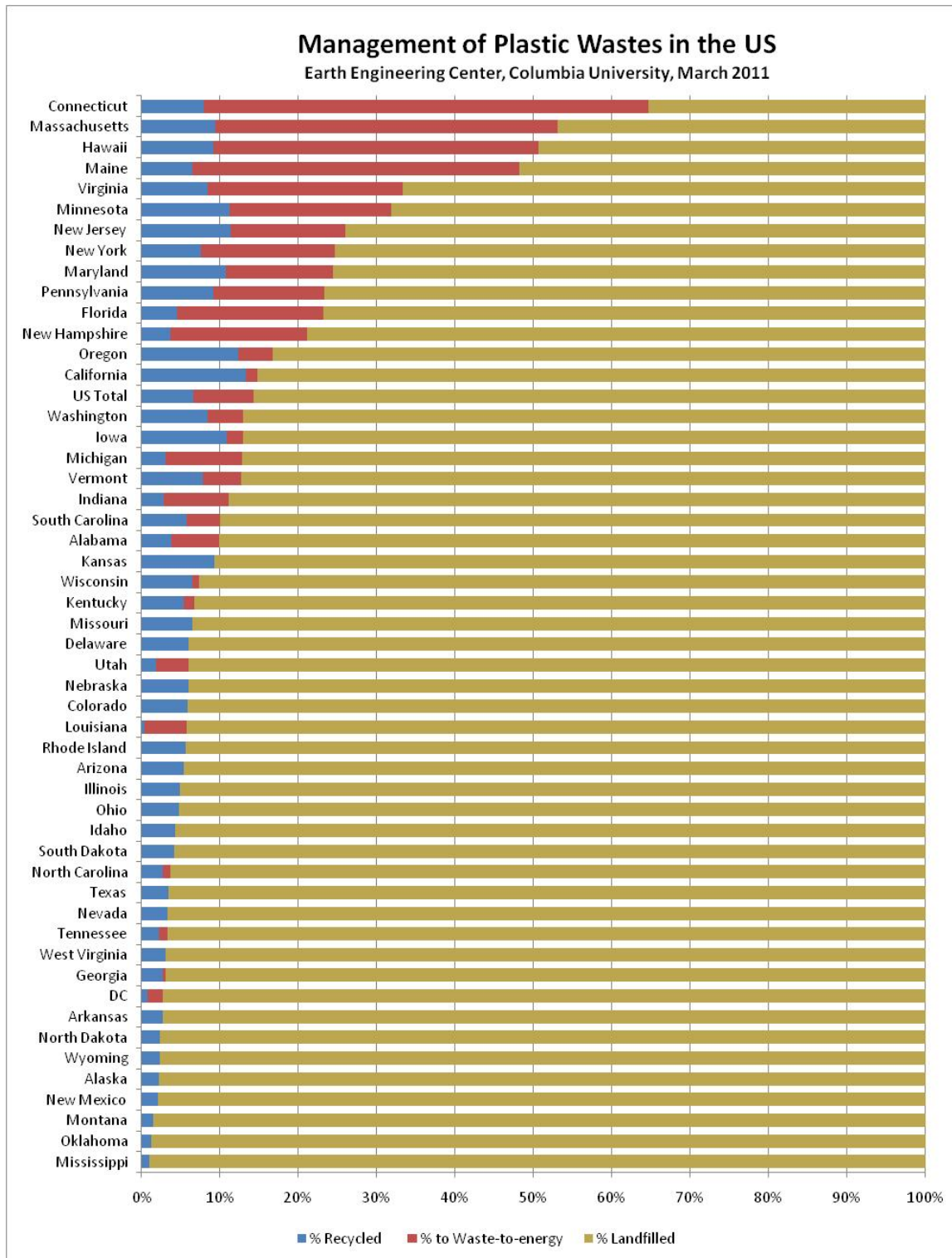Figure 5 Fraction of plastic recovered as materials or energy in each state
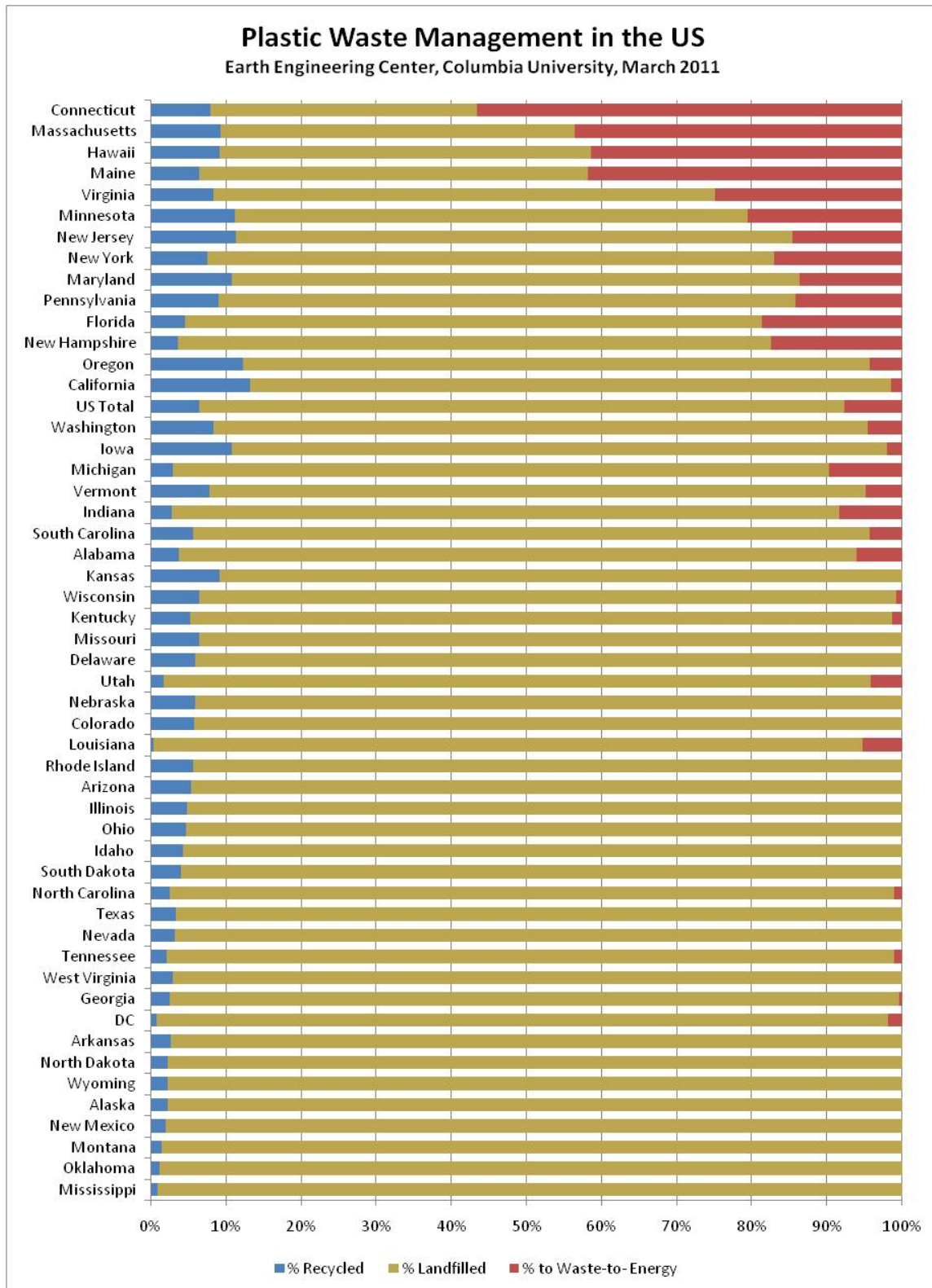
Plastic Waste Management in the US
Earth Engineering Center, Columbia University, March 2011

Figure 6 Position of each state on the "ladder" of sustainable management of plastics

5   POTENTIAL FOR ENERGY RECOVERY FROM NRP THAT ARE NOW LANDFILLED

There are three main ways for recovering the energy value in NRP:

1) Pyrolysis of source-separated plastics that are currently landfilled. A recent study by the Earth Engineering Center for Flexible Packaging Association showed that some pyrolysis technologies are reaching commercialization in the United States and the conversion of non-recycled plastics directly to fuel oil is becoming a reality.

2) Use of source-separated plastics as fuel in dedicated power plants and/or as a fuel at cement kilns and industrial and commercial boilers, in place of fossil fuels.

3) Increasing U.S. WTE capacity: Since NRP are currently mixed in municipal solid wastes (MSW), one way to recover their chemical energy is by increasing the U.S. waste-to-energy (WTE) capacity from its present level of about 10% of the post-recycled MSW (27 million tons). This will have two distinct benefits: Energy will be recovered both from plastics and from the other combustible materials in MSW, and there will be a reduction of the greenhouse gas (GHG) emissions associated with landfilling. For example, replacing 25% of the current U.S. landfilling by new WTE capacity (i.e., 68 million tons of MSW) will result in the annual production of about 41 million MWh of electricity, sufficient for 4.1 million households.

5.1   Energy value of non-recycled plastics

A critical part of this study was to quantify the chemical heat contained in mixed plastic wastes (i.e., calorific value) that are currently being landfilled. Table 6 is based on data provided by the Energy Information Administration of the Department of Energy (DOE-EIA) and includes the heat content of various components of the non-recycled plastics (ref. 15, 25) and the tons of NRP generated as per the EPA report (Table 1, ref. 19). It should be noted that the DOE-EIA estimates are based on calorific values of actual non-recycled plastics, i.e. those containing a certain amount of other materials and some moisture that lower the heating value of the resin. This analysis showed that the Lower Heating Value (LHV), i.e., not including the latent heat of condensation of water vapor in the combustion gases, of non-recycled plastics is about 32 MJ/kilogram (Table 6).

Table 6 Calculation of Lower Heating Value of Non-recyclable Plastics in Municipal Solid Waste (MSW; ref. 15, 20)

Materials	Million Btu per Ton	MJ/kg	Tons in NRP stream	% in NRP	MJ/kg NRP
Polyethylene terephthalate (PET)	20.5	24	3,740	12.40%	2.93
High density polyethylene (HDPE)	38	44	5350	17.8%	7.76
Polyvinyl chloride (PVC)	16.5	19	1,660	5.50%	1.05
Low density polyethylene/ Linear low density polyethylene (LDPE/LLDPE)	24	28	5,880	19.60%	5.39
Polypropylene (PP)	38	44	4,190	13.90%	6.08
Polystyrene (PS)	35.6	41	2,620	8.70%	3.56
Other	22	25	6,610	22.00%	5.55
Total NRP			**30,050**	**100%**	31.96

5.2 Energy equivalence of NRP to coal, oil, and natural gas

The value of 31.96 MJ/kg (Table 6) corresponds to 14,000 Btu/lb (28 million Btu/ton) and was used in the following calculations. In comparison, the fossil fuels used in the U.S. have the following LHV values:

- Natural gas: 20,300 Btu/lb
- Crude oil: 18,400 Btu/lb
- Non-recycled plastics (NRP)   14,000 Btu/lb
- Petroleum coke: 12,700 Btu/lb
- U.S. coals: 9,800-11,200 Btu/lb
- Wood: 6,000 Btu/lb

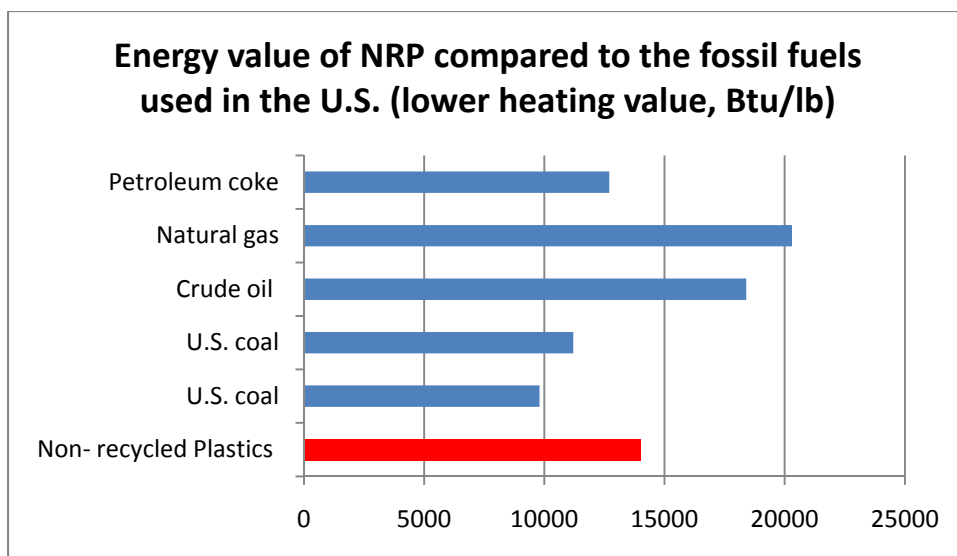Figure 7 is a bar chart comparing the heating values of these fuels.

Figure 7 Comparison of heating value of NRP to that of other fuels

Table 7 shows the tons of coal, barrels of oil and cubic feet of natural gas of equivalent heating value to the tons of NRP currently landfilled in each state. The heating values used in calculating the equivalence were as follows:

1 ton NRP: 28 million Btu; 1 ton coal: 22 million Btu; 1 barrel oil: 5.8 million Btu; 1000 standard cubic feet of natural gas: 1.03 million Btu

Table 7 Fossil fuel equivalent quantities to tons of NRP landfilled in each state

State	Tons of NRP to landfills	MBtu lost in NRP landfilled (at 28 million Btu/ton)	Tons of coal equivalent to NRP heating value	Barrels of oil equivalent to NRP heating value	Natural gas equivalent to NRP heating value, in 1000 standard cubic feet
Alabama	463,972	12,991,226	590,510	2,239,867	12,612,841
Alaska	74,133	2,075,735	94,352	357,885	2,015,277
Arizona	679,543	19,027,205	864,873	3,280,553	18,473,015
Arkansas	307,106	8,598,966	390,862	1,482,580	8,348,511
California	3,461,357	96,918,008	4,405,364	16,710,001	94,095,154
Colorado	514,199	14,397,560	654,435	2,482,338	13,978,214
Connecticut	137,019	3,836,538	174,388	661,472	3,724,794
Delaware	90,691	1,781,170	80,962	307,098	1,729,291
DC	63,613	2,539,355	115,425	437,820	2,465,393
Florida	1,555,831	43,563,272	1,980,149	7,510,909	42,294,439
Georgia	1,037,964	29,062,991	1,321,045	5,010,861	28,216,496
Hawaii	70,309	1,968,651	89,484	339,423	1,911,311
Idaho	161,164	4,512,599	205,118	778,034	4,381,164
Illinois	1,356,959	37,994,853	1,727,039	6,550,837	36,888,207

20

Indiana	626,154	17,532,320	796,924	3,022,814	17,021,669
Iowa	288,798	8,086,357	367,562	1,394,200	7,850,832
Kansas	280,966	7,867,055	357,593	1,356,389	7,637,918
Kentucky	440,220	12,326,155	560,280	2,125,199	11,967,141
Louisiana	459,521	12,866,593	584,845	2,218,378	12,491,838
Maine	75,316	2,108,854	95,857	363,596	2,047,431
Maryland	470,770	13,181,556	599,162	2,272,682	12,797,627
Massachusetts	337,427	9,447,950	429,452	1,628,957	9,172,767
Michigan	964,192	26,997,366	1,227,153	4,654,718	26,211,035
Minnesota	393,313	11,012,766	500,580	1,898,753	10,692,006
Mississippi	321,446	9,000,490	409,113	1,551,809	8,738,340
Missouri	610,826	17,103,116	777,414	2,948,813	16,604,967
Montana	105,373	2,950,442	134,111	508,697	2,864,507
Nebraska	185,382	5,190,692	235,941	894,947	5,039,506
Nevada	277,853	7,779,887	353,631	1,341,360	7,553,288
New Hampshire	114,730	3,212,441	146,020	553,869	3,118,875
New Jersey	710,290	19,888,115	904,005	3,428,985	19,308,849
New Mexico	214,852	6,015,849	273,448	1,037,215	5,840,630
New York	1,623,437	45,456,246	2,066,193	7,837,284	44,132,278
North Carolina	981,457	27,480,792	1,249,127	4,738,068	26,680,381
North Dakota	69,239	1,938,705	88,123	334,259	1,882,238
Ohio	1,209,295	33,860,247	1,539,102	5,837,974	32,874,026
Oklahoma	397,517	11,130,480	505,931	1,919,048	10,806,291
Oregon	348,913	9,769,566	444,071	1,684,408	9,485,016
Pennsylvania	1,055,040	29,541,121	1,342,778	5,093,297	28,680,700
Rhode Island	109,555	3,067,542	139,434	528,887	2,978,196
South Carolina	445,367	12,470,281	566,831	2,150,048	12,107,068
South Dakota	85,200	2,385,591	108,436	411,309	2,316,108
Tennessee	664,223	18,598,232	845,374	3,206,592	18,056,536
Texas	2,596,488	72,701,665	3,304,621	12,534,770	70,584,141
Utah	284,250	7,959,004	361,773	1,372,242	7,727,188
Vermont	59,970	1,679,149	76,325	289,508	1,630,242
Virginia	572,424	16,027,866	728,539	2,763,425	15,561,035
Washington	629,797	17,634,308	801,559	3,040,398	17,120,688
West Virginia	194,444	5,444,440	247,475	938,697	5,285,865
Wisconsin	576,298	16,136,349	733,470	2,782,129	15,666,359
Wyoming	57,498	1,609,937	73,179	277,575	1,563,045
Total	**28,811,702**	**806,727,655**	**36,669,439**	**139,090,975**	**783,230,733**

Figure 8 and Figure 9 show the tons of coal equivalent to tons of NRP landfilled in states that import a large amount of coal. Figure 10 is based on Table 9 Table 9 2009 U.S. coal consumption and production by state, in APPENDIX 1 and shows the states that import coal, the tons of coal imported, and the tons of NRP that could be used to replace an equal amount of coal that is now imported.
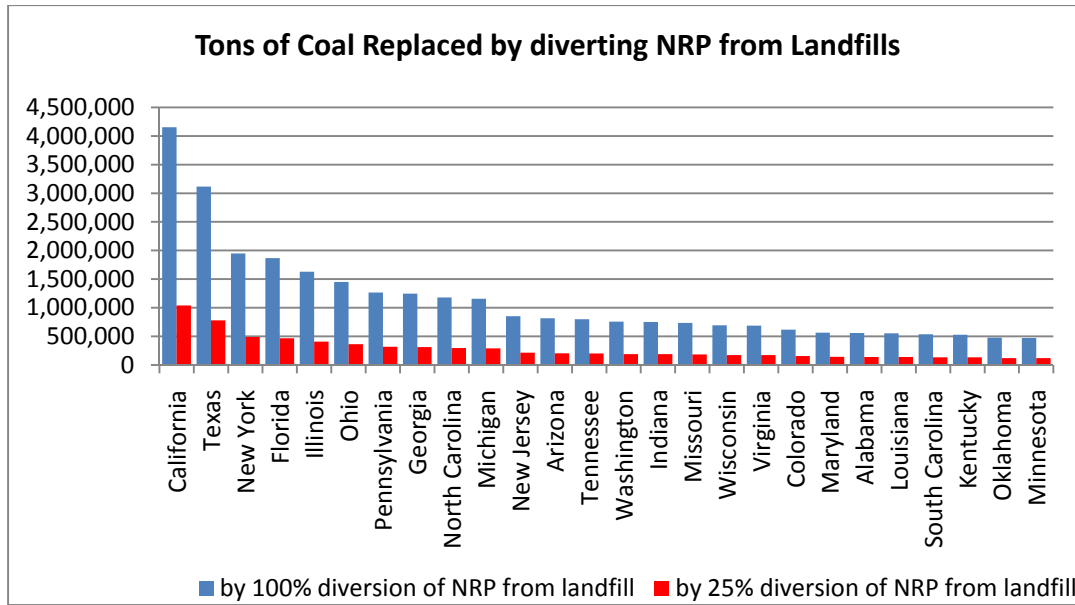
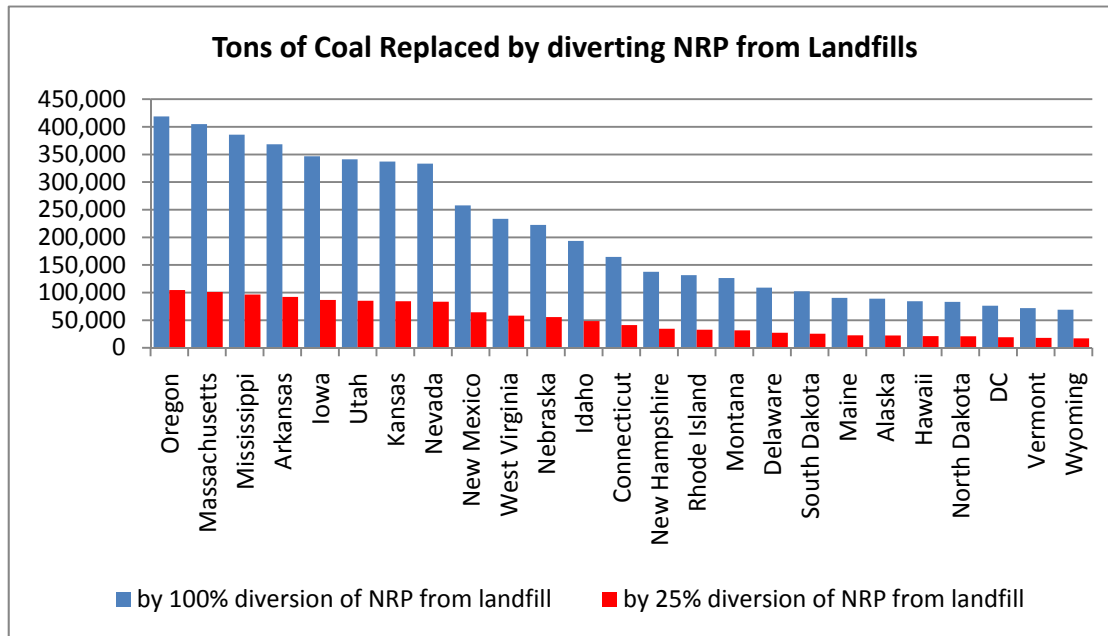Figure 8 Potential for replacing coal in states landfilling more NRP

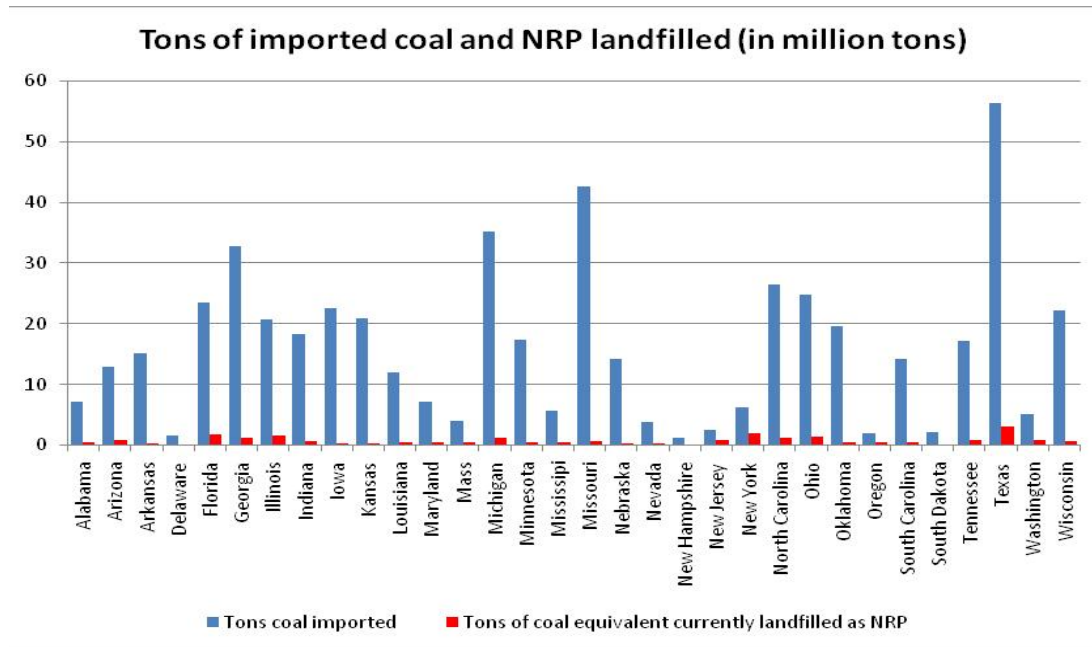Figure 9 Potential for replacing coal in states landfilling less NRP

Figure 10 Potential for NRP to replace coal in states that import coal

5.3 Transforming of NRP to oil by means of pyrolysis

Non-recycled plastics can be source-separated and converted to a crude oil or other types of fuel oil by a thermal treating technique called pyrolysis. Several companies are developing various processes that can pyrolyze NRP into synthetic oils (e.g. Envion, Climax Global Energy, Agilyx, JBI). A conservative estimate is that these processes, when fully industrialized, can convert one ton of NRP to 3 barrels of oil. Hypothetically, the 29 million tons of NRP in the MSW stream that are now landfilled could be converted to 87 million barrels of oil. This corresponds to 3.6 billion gallons, which would be enough fuel to power six million cars for one year. Figure 11 shows the potential of converting the non-recycled plastics to synthetic oil, for each State.

The economic value of 87 million barrels of synthetic oil, at current oil prices, would be 8.7 billion dollars.
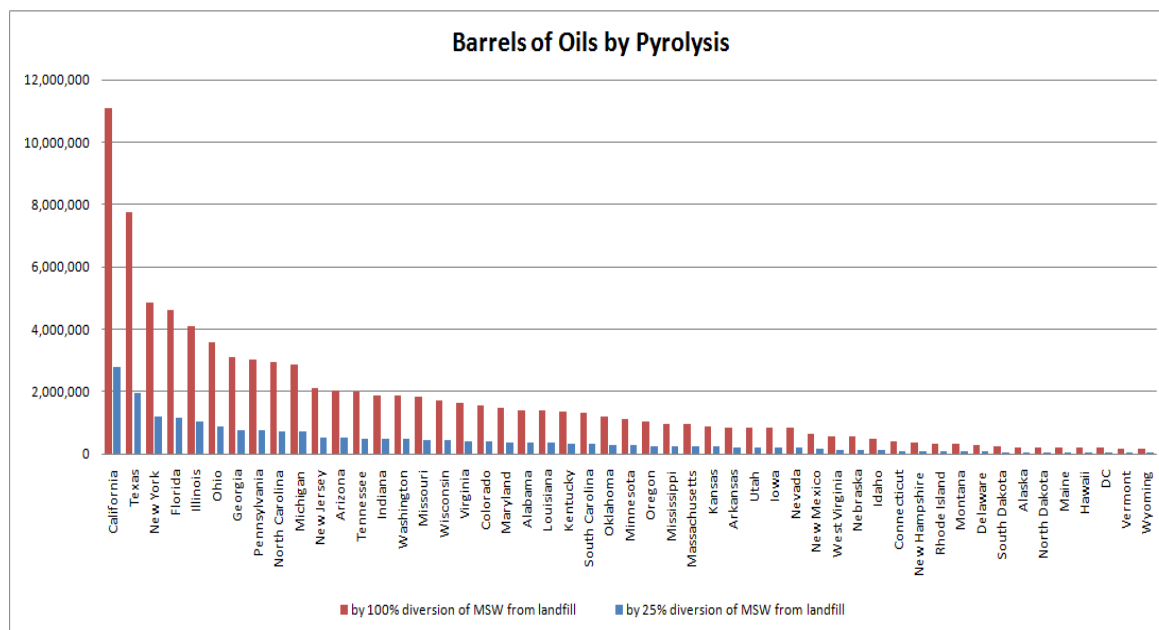
Figure 11 Potential for synthetic oil production by pyrolysis of source separated NRP

5.4 Potential of using source-separated NRP in dedicated power plants

Another way to use source-separated non-recycled plastics is by combustion in specially designed power plants to produce electricity. New waste-to-energy plants produce over 0.6 MWh per ton of MSW. However, NRP have an average calorific value (32 MJ/kg) that is, three times higher than the typical MSW. Therefore, it is estimated that NRP-dedicated power plants would be able to produce a net of 1.8 MWh per ton of NRP combusted. For a hypothetical 100% utilization of source-separated NRP in such power plants, the net electricity produced would be about 52 million MWh, sufficient for supplying 5.2 million households.

5.5 Increased utilization of NRP by means of increased U.S. waste-to-energy capacity

This study showed that 2.6 million tons of NRP are used beneficially in 87 waste-to-energy facilities across the nation that combust MSW and produce electricity. This amount represents only 7.7% of the total plastic generated in the U.S. since most of the NRP in MSW are not source-separated. An obvious way to increase the energy recovery of plastic is to increase the national WTE capacity. This section examines the potential of increasing the existing WTE capacity and what it would mean for the displacement of coal.

On the average, the existing WTE plants in the U.S. produce electricity (0.5 MWh/ton MSW) that avoids the mining of 1/3 ton of coal per ton of MSW combusted. These plants were built nearly twenty years ago and by now the technology has advanced to the point that new WTE facilities can produce a net of 0.6 MWh/ton of MSW, which corresponds to

replacing about 0.4 tons of coal per ton of MSW fuel. Hypothetical diversion of the 270 million tons of MSW that are currently landfilled (Table 3) would result in the generation of 162 million MWh, sufficient to supply 16.2 million households and reduce coal consumption by 108 million tons. Figure 12 shows graphically the replacement of coal consumption, state-by-state, by replacing 100% or 25% of the current landfilling by waste-to-energy.

Using a "home-grown" fuel in place of imported coal will be of particular interest to states that import large amounts of coal and export large quantities of MSW to other states for landfilling. Figure 13 is partly based on Table 9 of APPENDIX 1 ("2009 U.S. coal consumption and production by state") and shows the states that import coal, the tons of coal imported, and the tons of MSW landfilled, either within the state or in other states. For these states, there is an additional advantage of installing WTE capacity and using a home grown fuel, thus reducing the importation of coal.
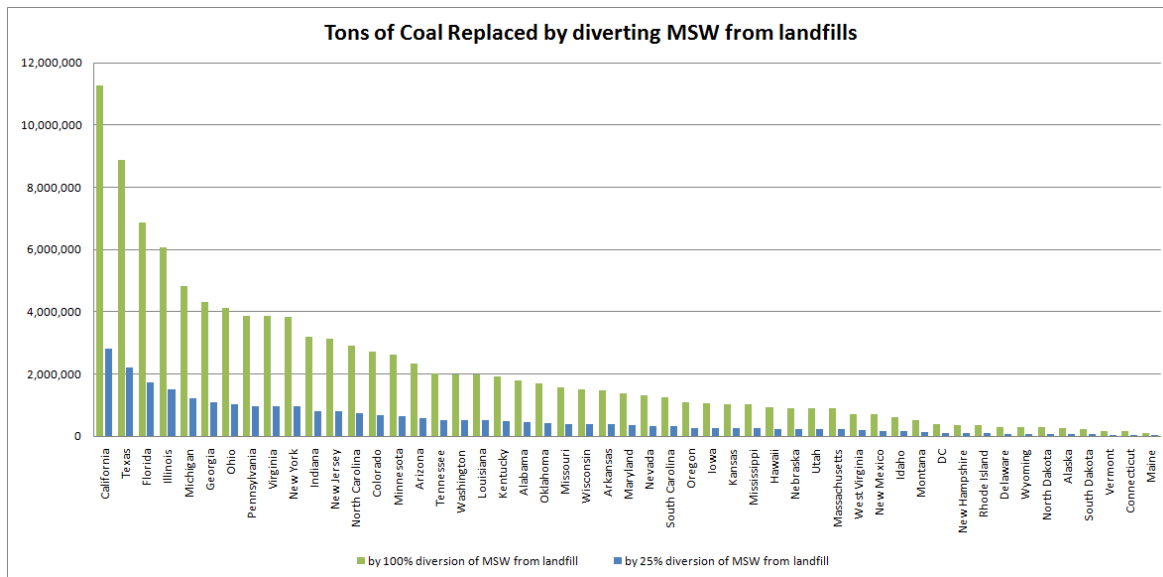

Figure 12 Potential for replacing coal by diverting 100 % and 25 % of MSW from landfilling to WTE
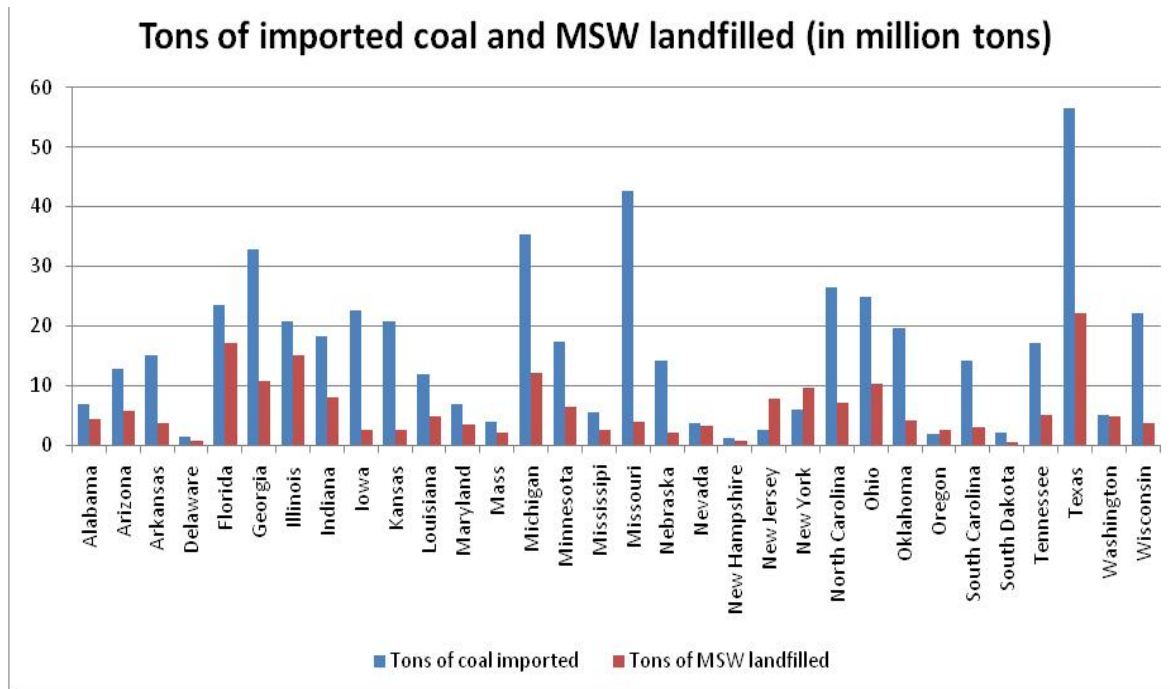
Figure 13 Tons of coal imported and tons of NRP-MSW mix landfilled in the fifty states

5.6 Greenhouse gas (GHG) benefit of increasing WTE capacity

In addition to recovering the energy content of plastics contained in MSW, increasing the WTE capacity of the U.S. will also result in a significant reduction of the emission of greenhouse gas (GHG) effect. One ton of MSW diverted from landfilling to WTE reduces GHG emissions by 0.5 to 1 ton of carbon dioxide equivalent, depending on the degree of landfill gas capture. Figure 14 shows the beneficial GHG effect, in each state, of combusting 25% and 100% of MSW that is presently landfilled. Several states have recognized this environmental advantage of WTE. Most recently, Maryland enacted legislation that moved WTE to Tier 1 of renewable energy sources, alongside wind and solar energy.
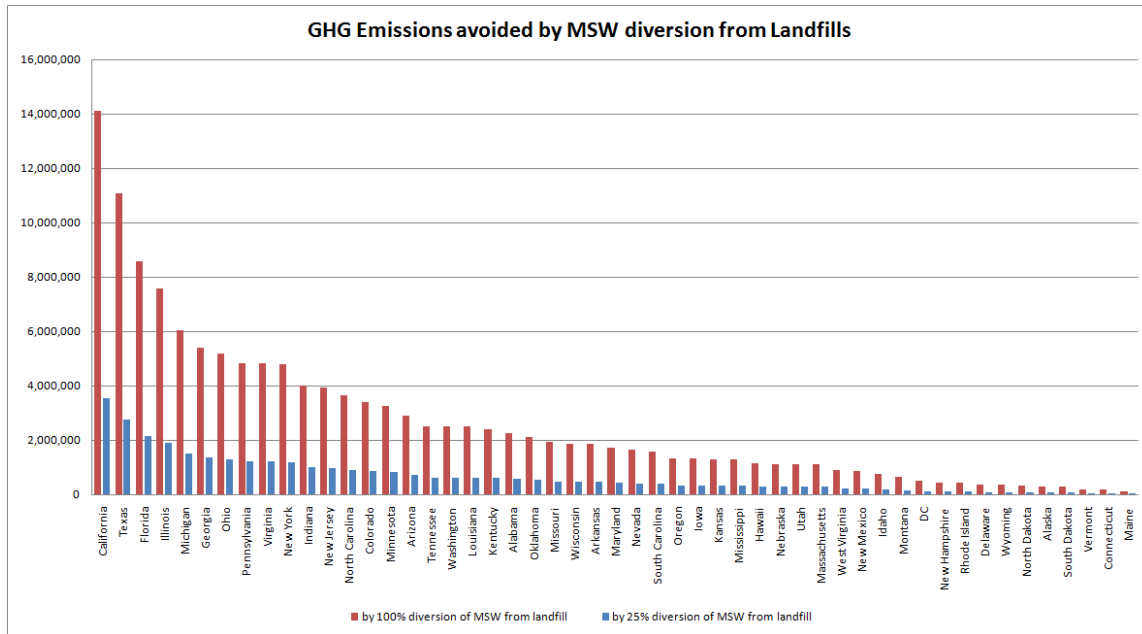
Figure 14 GHG benefit of diverting 25% and 100% of MSW landfilled to WTE

As noted earlier, the net production of electricity from new WTE facilities in the U.S. is estimated at 0.6 MWh per ton of MSW combusted. Figure 15 shows the projected production of electricity in each state by diverting 25% and 100% of the present landfilling to new WTE facilities. Because of the rising costs of fossil fuels and the fact that over 50% of the energy contained in MSW is biogenic and thus renewable energy, the value of new WTE electricity is estimated at $100/MWh.

Figure 16 shows the economic value of the WTE electricity that can be produced from WTE in each state. By utilizing just 25% of the current MSW that is landfilled via new WTE capacity would result in the annual production of 40 million MWh of electricity, sufficient for the needs of about 4 million households. The value of this energy, at an assumed $100/MWh, is four billion dollars. Eventual replacement of all U.S. landfilling by WTE would result in annual production of 160 million MWh of electricity, enough to supply 16 million households.
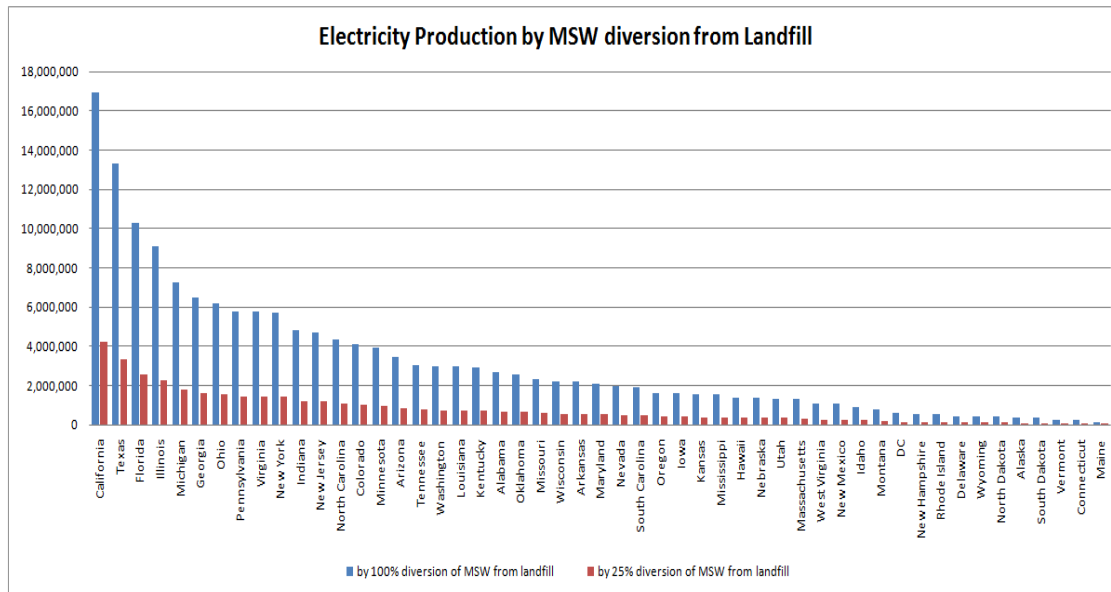
Figure 15 Electricity production by diverting 25% and 100% of present landfilling to new WTE facilities
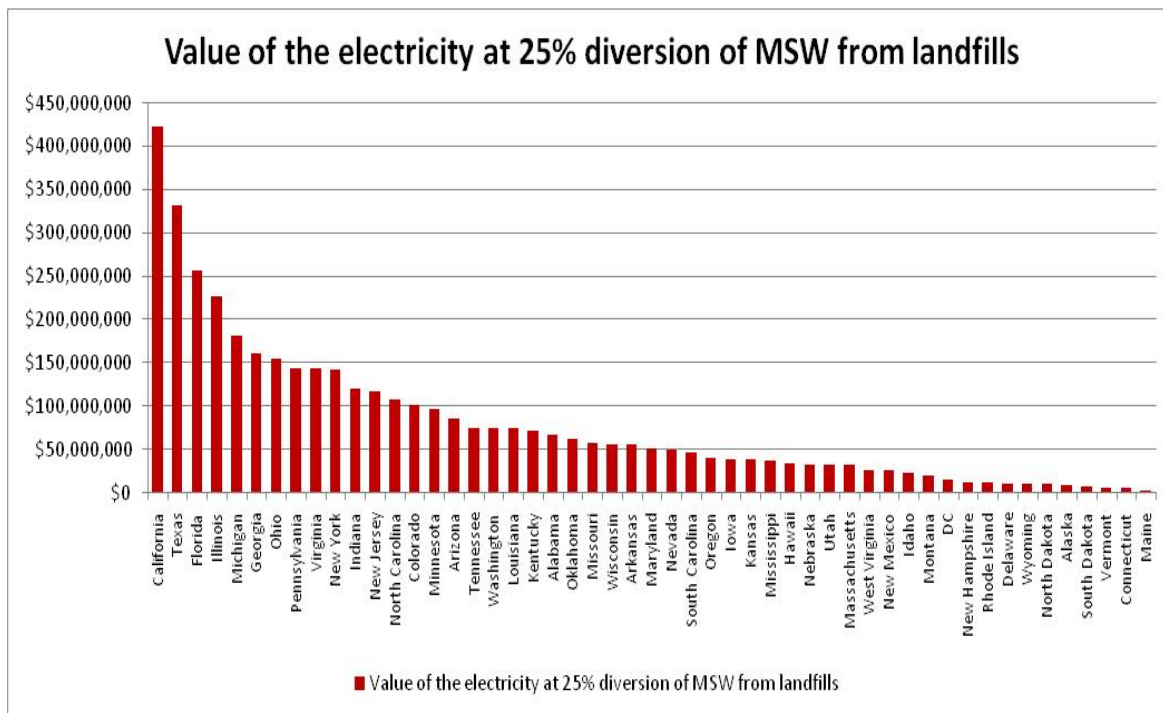

Figure 16 Value of electricity (at $100/MWh) produced by diverting 25% of present landfilling to new WTE facilities

CONCLUSIONS

- The results of this study showed that 6.5% of the used plastics generated in the U.S. are recycled, 7.7% are combusted with energy recovery, and the remaining 85.8% are landfilled. The states closest to sustainable waste management of plastics in 2008, by complementing recycling with energy recovery, are Connecticut, Massachusetts, Hawaii, Maine, Virginia, and Minnesota; the diversion rates of NRP from landfills in these states, by recycling and combustion with energy recovery, range from 65% for Connecticut to 32% for Minnesota.

- The amount of NRP plastics landfilled in the United States in 2008 was estimated at 28.8 million tons. The chemical energy contained in this material was 807 trillion Btu. This amount of energy is equivalent to:

  - 36.7 million tons of coal, or
  - 139 million barrels of oil, or
  - 783 billion cubic feet of natural gas

- Hypothetically, if all the NRP that are currently landfilled were source-separated and converted by pyrolysis to a fuel oil, they would produce an estimated 87 million barrels of oil per year (3.6 billion gallons), enough to power six million cars for one year.

- If all the NRP that are landfilled annually were to be source-separated and used as fuel in specially designed power plants, the electricity produced would be 52 million MWh, enough to supply 5.2 million households. This would also reduce U.S. coal consumption by as much as 34 million tons.

- Hypothetically, if 100% of the landfilled municipal solid wastes (MSW) were diverted from landfills to new WTE power plants, they would reduce coal consumption by 108 million tons and produce 162 million MWh of electricity, enough to power 16.2 million households for one year.

- This study also examined the effect of new WTE capacity on reducing coal consumption in states that now import large amounts of coal. As stated above, one ton of MSW used as fuel in <u>new</u> WTE plants would produce the energy equivalent of about 0.4 tons of coal. Accordingly, 25% diversion of MSW currently landfilled to new WTE plants would avoid the mining of 27 million tons of coal and as much as 270 million tons of overburden; 100% diversion of current landfilling by means of new WTE capacity would reduce coal mining by 108 million tons of coal, nearly 10% of the U.S. coal consumption.

- Lastly, increased WTE capacity would reduce the carbon footprint of waste management in the U.S. For example, a 25% diversion of mixed biomass and NRP

in MSW from landfills to new WTE facilities will result in greenhouse gas (GHG) reduction of 35 to 70 million tons of carbon dioxide equivalent, depending on the degree of landfill capture in present landfills.

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APPENDIX 1

a) Characterization of U.S. Plastic Stream

One of the most detailed characterizations of the plastic waste stream was carried out in California in 2003 and is shown in Table 8.

Table 8 Composition of plastic waste stream of California (2003)

Type of plastic waste	Tons in disposed MSW	% of plastic stream
PETE Containers	199,644	5.2%
HDPE Containers	157,779	4.1%
Miscellaneous Plastic Containers	163,008	4.3%
Plastic Trash Bags	361,997	9.5%

Plastic Grocery and Other Merchandise Bags	123,405	3.2%
Non-Bag Commercial and Industrial Packaging Film	194,863	5.1%
Film Products	113,566	3.0%
Other Film	554,002	14.5%
Durable Plastic Items	834,970	21.9%
Other and Composite Plastic	1,104,719	29.0%
Total plastic waste stream	**3,807,952**	100.0%

b) Coal consumption and imports by state

Table 9 shows tons of coal consumed, coal mined, and coal imported by state.

Table 9 2009 U.S. coal consumption and production by state,

in million short tons (EIA)

State	Tons coal consumed	Tons coal mined	Tons coal imported
Alabama	27.6	20.6	7
Arizona	20.8	8	12.8
Arkansas	15		15
Delaware	1.4		1.4
Florida	23.5		23.5
Georgia	32.8		32.8
Illinois	53.7	33	20.7
Indiana	54.5	36.2	18.3
Iowa	22.6		22.6
Kansas	20.8		20.8
Louisiana	15.7	3.8	11.9
Maryland	9.8	2.8	7
Massachusetts	3.9		3.9
Michigan	35.3		35.3
Minnesota	17.4		17.4
Mississippi	8.4	2.8	5.6

Missouri	42.7		42.7
Nebraska	14.2		14.2
Nevada	3.8		3.8
New Hampshire	1.2		1.2
New Jersey	2.5		2.5
New York	6.1		6.1
North Carolina	26.4		26.4
Ohio	51.1	26.3	24.8
Oklahoma	21	1.4	19.6
Oregon	1.9		1.9
South Carolina	14.1		14.1
South Dakota	2.1		2.1
Tennessee	19.5	2.3	17.2
Texas	95.4	39	56.4
Washington	5		5
Wisconsin	22.2		22.2
U.S. total	**933.8**	**176.2**	**757.6**

c)

c)

c) Annual electricity consumption in U.S.: 10,656 kWh/household

(www.eia.doe.gov/emeu/reps/enduse/er01_us_tab1.html)